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MAGNETIC FIELD DRAPING ABOUT CORONAL MASS EJECTA

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Abstract

Fast coronal mass ejecta (CMEs) accelerate and deflect the slower moving solar wind plasma which piles up ahead of them as they propagate out through the heliosphere. This acceleration and deflection, in turn, causes the interplanetary magnetic field (IMF) imbedded in the upstream solar wind to drape about the ejecta. Draping should cause substantial out-of-the-ecliptic magnetic fields at some locations ahead of CMEs, and radial fields behind and along the flanks. At the Earth, draping can be an important factor in the generation of some magnetic storms and substorms, while in the outer heliosphere draping may produce very large magnetotail-like configurations, somewhat analogous to those observed behind Venus and comets.

Introduction

Over the past three decades magnetic field draping has been identified at numerous bodies throughout the solar system. Draping is responsible for the magnetotails at Comet Giacobini-Zinner [e.g., Slavin et al., 1986; McComas et al., 1987a] and Venus [e.g., Russell et al., 1981; McComas et al., 1986], the average field configuration in the terrestrial magnetosheath [e.g., Luhmann et al. 1984; Crooker et al., 1985], the deflection of the terrestrial magnetotail lobe field (traveling compressional regions) during the passage of plasmoids down the tail [Slavin et al., 1984], and the bending of the Jovian magnetic field about Io [e.g., Acuna et al., 1981 and references therein].

Magnetic field draping is caused by slowing and diversion of a magnetized plasma in the regions surrounding magnetized and conducting obstacles. For example, the very high solar wind electrical conductivity [e.g., Parker, 1958] requires that the solar wind plasma and IMF be substantially excluded from the magnetospheres and ionospheres of planets and comets. Draping, as it occurs at Venus, is shown schematically in Figure 1. The draped field lines are projected into the plane defined by the upstream solar wind flow velocity and IMF vectors, and passing through the center of the planet. The magnetized solar wind piles up upstream from the planet causing pressure gradients which act to slow, compress, and deflect this plasma. Meanwhile, far from the planet, the plasma flows along unimpeded. The velocity shear between magnetically linked parcels of plasma which experience differing amounts of slowing and deflection causes the imbedded field to become draped about the obstacle. Ultimately, the hung-up field slips over and under the planet (into and out of the page in Figure 1) and into the draped magnetotail.

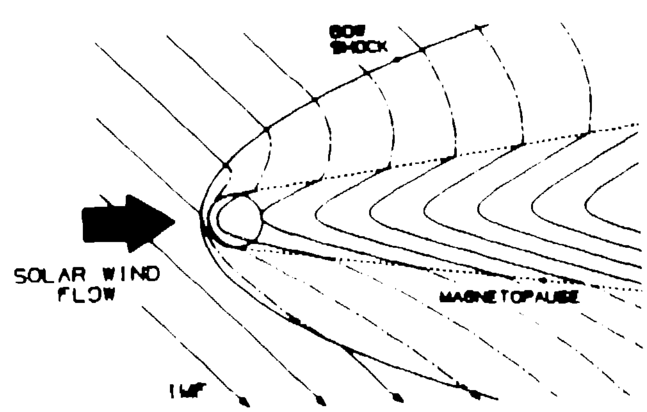

Fig. 1. Magnetic field draping at Venus projected into the plane defined by the upstream solar wind velocity vector and IMF, and passing through the center of the planet. From McComas et al. [1986]

Coronal mass ejections (CMEs) are eruptions of magnetized coronal and chromospheric material which propagate out into interplanetary space as distinct magnetic structures. CMEs have been observed with coronagraphs near the limb of the sun for many years [e.g., Hundhausen et al., 1984, and references therein], and can often be distinguished in interplanetary data at 1 AU by their anomalous composition, thermal, phase space, and field signatures (see, for example, Gosling et al. [1987a, b] and references therein). The very high electrical conductivity both within CMEs and upstream prevents any substantial interpenetration of these magnetically distinct regions. Therefore, when a fast CME plows out through slower moving solar wind, the upstream plasma is accelerated and diverted away from its path causing draping of the imbedded upstream IMF.

This brief paper summarizes our two previous studies on the subject of IMF draping about fast CMEs: Gosling and McComas [1987] which concentrated on draping about CMEs as a source of out-of-the-ecliptic magnetic fields at 1 AU, and therefore geomagnetic activity, and McComas et al. [1987b] which examined magnetic field draping about fast CMEs in the outer heliosphere where draping should lead to large magnetotail-like structures.

Field Draping Near 1AU

We calculate the draped IMF configuration about fast CMEs by determining the locations on the sun from which quiescent upstream solar wind and fast CMEs originated. All field lines initially to the west of the CME origin location are assumed to remain hung-up on the CME. At least near 1 AU and beyond, magnetic flux is expected to remain hung-up on CMEs for a long time due to 1) the large size and expansion of the CME as it propagates out from the sun, and 2) the relatively small transverse flow speeds generally observed upstream from such bodies near 1 AU. The resultant draped configuration can then be qualitatively drawn in an ecliptic plane cut, as is done in Figure 2 for a 600 km s^{-1} CME at 1 AU in a 400 km s^{-1} background solar wind flow.

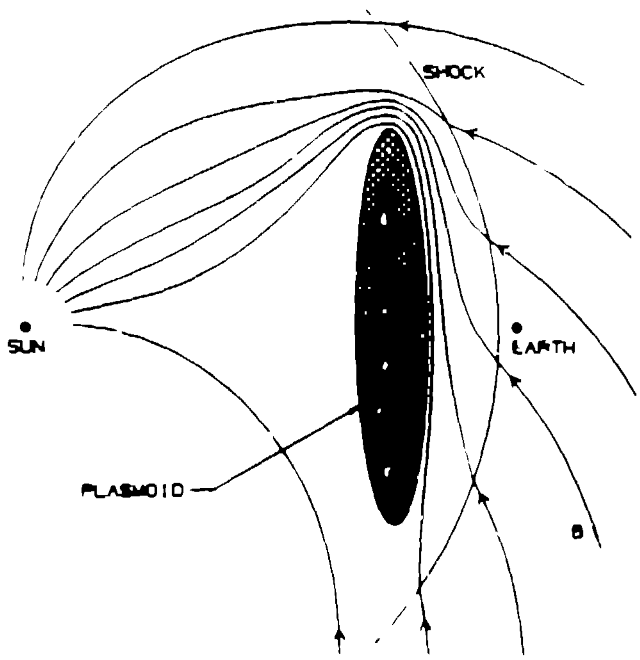

Fig. 2. Idealized sketch, in the solar equatorial plane, of IMF draping about a 600 km s^{-1} CME (cross-hatched) in a 400 km s^{-1} solar wind near 1 AU. From Gosling and McComas [1987].

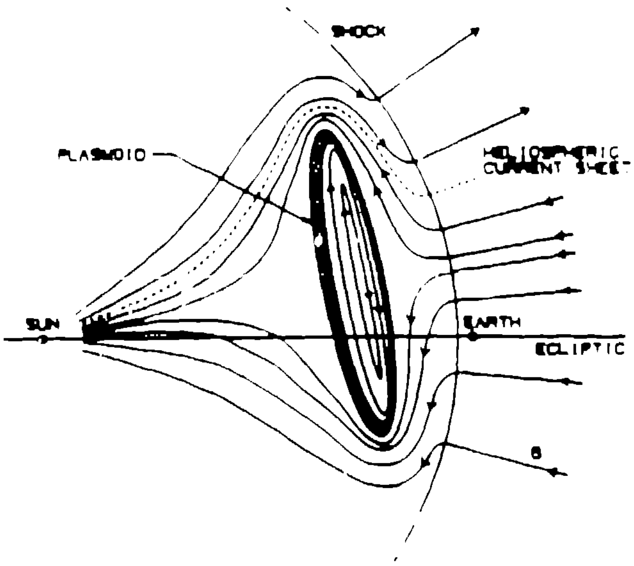

Fig. 3. Idealized sketch, in a solar meridional plane, illustrating the north-south draping of a purely radial IMF about a fast CME. From Gosling and McComas [1987].

Figure 3 shows the expected draping of a purely radial upstream IMF about a fast CME near 1 AU in a solar meridional plane. Acceleration and deflection of the solar wind plasma ahead of the CME causes the radial component of the IMF to drape away from the center of the CME as shown. Note that draping of the radial component of the IMF can cause substantial northward and southward B_z upstream from a CME. In addition, draping of the transverse component of the upstream IMF can also yield enhanced B_z components as the hung-up field lines are carried away from the center of the CME. In general, draped configurations are topologically complicated, and the draped field at any location within the compressed ambient plasma upstream from a CME depends upon both of these effects. In actual observations, draping may often be partially masked by fluctuations ahead of such bodies.

Intervals of southward IMF are strongly correlated with intervals of enhanced geomagnetic activity (see, Baker et al. [1984], and references therein). Thus, the above discussion suggests that IMF draping about fast CMEs can be an important source of geomagnetic activity. This factor is, in principal, predictive, since the average draping pattern about CMEs can be modeled and the source regions can often be inferred from disk observations.

ISEE-3 plasma and magnetic field data (near 1 AU) for the passage of a CME on August 29-30, 1979 are displayed in Figure 4. The CME has been identified primarily by a bidirectional electron heat flux signature, but is also characterized by low ion temperatures and a relatively smooth magnetic field rotation. Note that the compressed, draped region between the shock and the CME contains a prolonged interval of strong southward IMF. In addition, the field in the leading portion of the CME is also strongly southward. We suggest that the largest geomagnetic storms are often associated with the passage of fast CMEs where draping produces southward fields in the plowed-up region ahead of the CME, and where the internal field in the compressed leading portion of the CME is also oriented southward at the location of the Earth as shown in Figure 3. In fact, the disturbance displayed in Figure 4 did produce a large geomagnetic storm and all of the large geomagnetic storms in the 1978-1979 era were associated with the passage of fast CMEs [Gosling et al., 1987a].

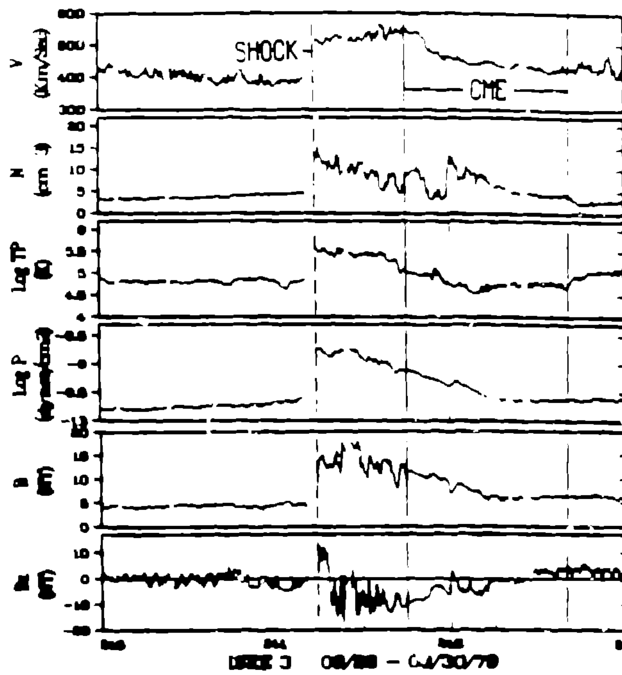

Fig. 4. ISEE-3 solar wind plasma and field parameters for August 28-30, 1979. Note the interval of strong southward B_z in the draped region between the shock (dashed line) and the leading edge of the CME (first solid line). From Gosling and McComas [1987].

Field Draping in the Outer Heliosphere

Beyond 1 AU draping effects should become increasingly pronounced as a CME continues to plow up the ambient IMF which is increasingly transversely oriented. Figure 5 displays our calculated draping of the quiescent spiral IMF (300 km s^{-1} solar wind) about a 800 km s^{-1} CME at ~9 AU in the ecliptic plane. While CME speeds of 800 km s^{-1} and above are not common at 1 AU, they have been observed [e.g., Gosling et al., 1987a]. For lower relative velocities between the CME and the upstream solar wind, the expected field draping is qualitatively similar, but less pronounced than that shown.

Note that draping produces relatively radial field orientations along the flanks of fast outer heliospheric CMEs. Sunward from such CMEs the field (dashed) should also be relatively radial. The field within the rarefied region behind such CMEs presumably encountered the CMEs near their tops and bottoms, became hung-up on the CME for a short while, and then slipped past the CME (in a manner similar to that at Venus, Figure 1). For very fast CMEs, as shown in Figure 5, draping should produce a tail-like configuration which resembles the draped magnetotail at Venus; however, in contrast to the Venus case, this "draped magnetotail" has a width and length of several AU and points back toward the sun rather than away from it.

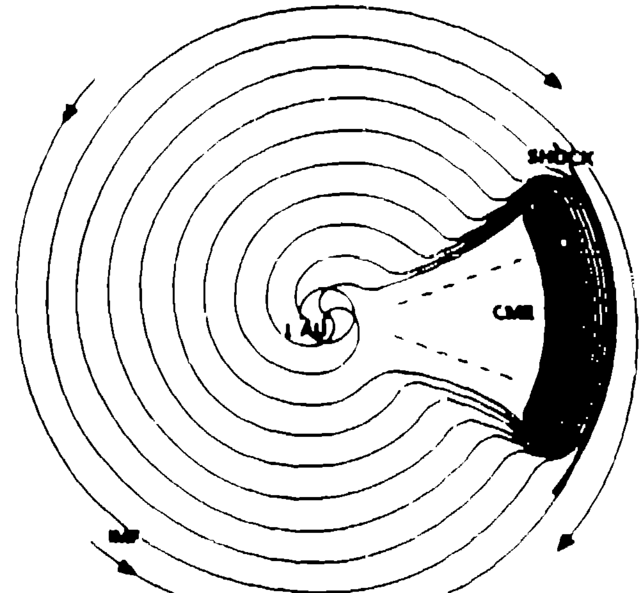

Fig. 5. Idealized sketch, in the solar equatorial plane, of IMF draping about a 800 km s^{-1} CME in a 300 km s^{-1} background solar wind near 9 AU. From McComas et al. [1987b].

In light of our expectations of field draping about CMEs in the outer heliosphere, we examined ~5800 one-hour averaged magnetic field vectors from the JPL magnetometer onboard Pioneer 11 covering the interval from May 5, 1978 (6.9 AU) through the end of 1979 (9.4 AU). This data set contains numerous examples of large scale fluctuations superposed on the average field variations [e.g., Smith and Barnes, 1983]. While the majority of the field enhancements preceded by interplanetary shocks at these large distances are associated with corotating stream interaction regions [e.g., Smith and Wolfe, 1979], transient structures are also observed.

Figure 6 displays the magnetic field observations for May 9-29, 1978 (~7.0 AU). The top panel shows the total field strength while the lower two panels display angles which are approximately the out-of-the-ecliptic angle (delta) and the spiral angle (phi) of the field. In the region 6.9 AU < R < 9.4 AU, the normal IMF spiral angles in the solar equatorial plane are within 10° of the transverse direction (phi = +/- 90°), so that regions where phi is near 0° and +/-180° constitute substantial deviations from the average configuration. Over the nearly two years of data examined, only ~18% of the phi values were within +/-45° of 0° or +/-180°, and only ~7% were within +/-20° of these values.

As shown in Figure 5, compressed, transversely oriented fields should be expected in the plowed-up regions ahead of fast CMEs, while extended regions of roughly radial fields should be expected in the draped regions along the flanks and behind. The field structure displayed in Figure 6 is quite consistent with the passage of an interplanetary shock (~1200 on day 131), a compressed, transversely oriented region of ambient magnetic field (days 131-133), and a fast CME (days 133-136). In the region following the passage of the CME (days 137-149) the field magnitude is depressed below the upstream, unshocked value, and the field orientation points alternately in roughly the radial and anti-radial directions for extended periods. Finally, fluctuations superpose substantial fine structure onto actual field observations such as those shown in Figure 6.

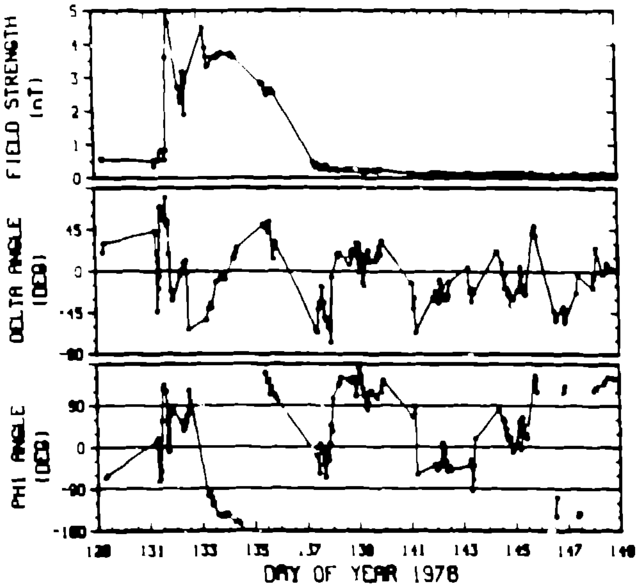

Fig. 6. Pioneer 11 magnetic field data for May 9-29, 1978 (7.0 AU). The structure shown displays all the expected signatures of the passage of a large, fast CME and the draped field about it (see text). From McComas et al. [1987b].

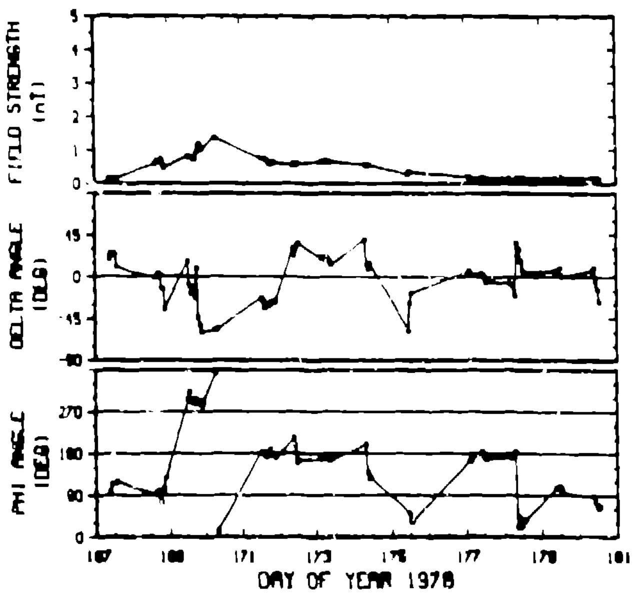

Fig. 7. Same format as the last figure, only this time for June 16-30, 1978 (7.2 AU). This signature is consistent with the passage of a CME which has already slowed to the background solar wind speed. From McComas et al. [1987b].

Figure 7 displays a similar set of magnetic field plots for the interval from days 167-181, 1978 (7.2 AU). While no interplanetary shock is observed at the start of the event, a field strength enhancement is observed (days 169-171), followed by a long and unusual interval of relatively radial fields (days 171-179). Such a signature is consistent with that expected for a CME which is no longer moving faster than the ambient solar wind, but rather is co-traveling outward with draped IMF which it accreted further in in the heliosphere.

Summary

The very length and nature of this brief paper has precluded the discussion of numerous important aspects of magnetic field draping about fast CMEs. The interested reader is urged to examine the more complete papers [Gosling and McComas, 1987; McComas et al., 1987b] on which this summary was based. In any case, the work described here indicates that 1) magnetic field draping about fast CMEs at 1 AU can contribute to the production of prolonged intervals of southward B_Z, and therefore also, geomagnetic storms and substorms, and 2) magnetic field draping about fast CMEs farther out in the heliosphere can cause huge, draped magnetotail-like structures and substantial intervals of relatively radial fields.

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References

Acuna, M.H., F.M. Neubauer, and N.F. Ness, Standing Alfven wave current system at Io: Voyager 1 observations, *J. Geophys. Res.*, *86*, 8513, 1981.

Baker, D.N., et al., Substorms in the magnetosphere, in *Solar Terrestrial Physics: Present and Future*, edited by D.M. Butler and K. Papadopoulos, Chapter 8, NASA Ref. Publ. 1120, Washington, D.C., 1984.

Crooker, N.U., et al., Magnetic field draping against the dayside magnetopause, *J. Geophys. Res.*, *90*, 3505, 1985.

Gosling, J.T. and D.J. McComas, Field line draping about fast coronal mass ejecta: A source of strong out-of-the-ecliptic interplanetary magnetic fields, *Geophys. Res. Lett.*, *14*, 355, 1987.

Gosling, J.T., et al., Bidirectional solar wind electron heat flux events, *J. Geophys. Res.*, *92*, 8519, 1987a.

Gosling, J.T., M.F. Thomsen, S.J. Bame, and R.D. Zwickl, The eastward deflection of fast coronal mass ejecta in interplanetary space, *J. Geophys. Res.* in press, 1987b.

Hundhausen, A.J., et al., Coronal transients and their interplanetary effects, in *Solar Terrestrial Physics: Present and Future*, edited by D.M. Butler and K. Papadopoulos, Chapter 6, NASA Ref. Publ. 1120, Washington, D.C., 1984.

Luhmann, J.G., et al., Mapping of the magnetosheath field between the magnetopause and the bow shock: Implications for magnetospheric particle leakage, *J. Geophys. Res.*, *89*, 6829, 1984.

McComas, D.J., H.E. Spence, C.T. Russell, and M.A. Saunders, The average magnetic field draping and consistent plasma properties of the Venus magnetotail, *J. Geophys. Res.*, *91*, 7939, 1986.

McComas, D.J., et al., The Giacobini-Zinner magnetotail: Tail configuration and current sheet, *J. Geophys. Res.*, *92*, 1139, 1987a.

McComas, D.J., J.T. Gosling, D. Winterhalter, and E.J. Smith, Interplanetary magnetic field draping about fast coronal mass ejecta in the outer heliosphere, submitted to *J. Geophys. Res.*, 1987b.

Parker, E.N., Dynamics of interplanetary gas and magnetic fields, *Astrophys. J.*, *128*, 664, 1958.

Russell, C.T., J.G. Luhmann, R.C. Elphic, and F.L. Scarf, The distant bow shock and magnetotail of Venus: Magnetic field and plasma wave observations, *Geophys. Res. Lett.*, *8*, 843, 1981.

Slavin, J.A., et al., Substorm associated traveling compression regions in the distant tail: ISEE-3 geotail observations, *Geophys. Res. Lett.*, *11*, 657, 1984.

Slavin, J.A., et al., Giacobini-Zinner magnetotail: ICE magnetic field observations, *Geophys. Res. Lett.*, *13*, 283, 1986.

Smith, E.J. and J.H. Wolfe, Fields and plasmas in the outer solar system, *Space Sci. Revs.*, *23*, 217, 1979.

Smith, E.J. and A. Barnes, Spatial dependences in the distant solar wind: Pioneers 10 & 11, in *Solar Wind 5*, edited by M. Neugebauer, *NASA Conference Publication 2280*, Washington, D.C., 1983.